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ROTATION OF THE EARTH, DEFORMATION OF THE EARTH'S CRUST, AND SOLAR ACTIVITY

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ROTATION OF THE EARTH, DEFORMATION OF THE EARTH'S CRUST, AND SOLAR ACTIVITY

N. N. Pavlov

ABSTRACT. Analysis of the results of observations of the annual periodicity in changes in the earth's velocity of rotation by time services during the period from 1956 to 1964, taking into account a possible relation between the earth's velocity of rotation and deformation of the earth's crust. It is concluded that short-period oscillations in the longitude of individual blocks of the earth's crust occur. These longitude oscillations are shown to be the consequence of a real movement of the individual blocks relative to each other. The importance of a systematic determination of the block movement in the upper part of the crust by means of astronomical observations is stressed. Certain patterns are noted in the variations in the longitude difference between Europe and America during three solar activity cycles - namely, near the maximum Europe is shifted westward relative to America, while near the minimum it is shifted eastward. A71-21671

In the opinion of the majority of geophysicists, the reason for the annual periodicity in the variations of the earth's rate of rotation about its axis consists of the interaction of atmospheric circulation with the earth's surface. Therefore, the question naturally arises, precisely where on the earth does the main exchange by rotational moments occur with the atmosphere? There is justification to assume that it occurs mainly in Asia. The atmosphere's seasonal circulation here is significantly greater than at other places. Asia is the highest continent, with the exception of Antarctica, and its surface is covered with numerous and the highest mountain ranges. But then the following question arises: does the earth under the influence of an applied force rotate like an absolutely rigid body or is its surface deformed? /30*

The presence of numerous fractures of the earth's crust indicates the possibility of deformations. It is not difficult to show that if the earth's crust were a continuous rigid body, then its elastic deformation under the influence of the small forces caused by winds would not be detectable from astronomical observations. If it is broken into separate blocks, which are /31
capable of being mutually shifted within small limits, then the deformation would not be elastic, but a shear or plastic deformation, and its magnitude would increase in proportion to the work of the force at the time it acted, i.e., it would be proportional to the change in the earth's rate of rotation or the change in the duration of the day. If one assumes that the force which changes the earth's rate of rotation is applied to Eurasia, then in case of an increase in the rate of rotation Eurasia would be displaced eastward relative to the other continents, and in case of a decrease, westward. The maximum eastward shift will correspond to the shortest days, and a maximum westward shift, to the longest days. The seasonal variations in the longitude difference between Greenwich, Ottawa, Paris, and Washington for 14 years from 1923 until 1936 were determined in N. Stoyko's paper [18]. In our opinion, the determinations of Greenwich and Ottawa are more reliable, since here the observations were performed on instruments of the same kind in the system of one and the same catalogue, and a small latitude difference will significantly decrease the effect of its errors. N. Stoyko's results show that actually in the case of a large rate of rotation of the earth, Greenwich shifts eastward relative to

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* Indicates pagination in the original text.

Ottawa, and in the case of a small rate of rotation, westward, which supports the assumption made. However, these results can also be explained by a difference in the seasonal error between Greenwich and Ottawa, in part the "wind effect", as proposed by Kruger [15].

An accurate determination of the seasonal variations in the longitude difference between Eurasia and America is difficult because of errors in the right ascensions of the reference catalogue stars and seasonal errors in the astronomical observations. It is possible to investigate the problem of possible variations in the longitudes of Eurasia and America with the help of a method which completely excludes the effect of errors which are regularly repeated year after year. Also, the annual seasonal longitude variation is excluded, but in return it is possible to determine more reliably the anomalous variations in the earth's rate of rotation and the corresponding longitude variations. The essence of the method lies in the fact that the differences taken for investigation are monthly average values of the atomic clock corrections of some time service between two successive years, corrected for the shift of the earth's pole. They are evidently free of catalog errors and seasonal errors, but a relative variation in the earth's rate of rotation between these two years and possible variations in the longitude of a given time service are included in these differences. Based on the results obtained by various time services, it is possible to judge the stability of their longitudes and the relation of their variations with the variations in the earth's rate of rotation. It is better to carry out the investigation by groups of territorially-related time services in order to decrease the effect of various errors. One can start them from 1956, which marks the beginning of operation of atomic time service. On the basis of data published by the Moscow Time Bureau, we carried out such comparisons for 1957 and 1956, 1959 and 1958, 1961 and 1960, and 1963 with respect to the average for 1962 and 1964. /32

Individual time services are grouped in the following way: the first group consists of all the time services operating on the USSR etalon time system, which comprises 14-18 services (abbreviated ET); this group corresponds approximately to Eurasia; the second group consists of Western European time services and comprises 5-8 time services (WE); the third group consists of the three North American time services (NA); and the fourth group consists of South American time services, which comprises 3-5 time services (A).

The mean annual value, also the relative variation corresponding to the system of atomic time corrections based on the Moscow Time Bureau cumulative instants, are eliminated from the differences of the average monthly atomic time corrections for convenience in reviewing the results. The values of the weighted mean differences ΔU_A are presented in Table 1 for these four groups for the four periods considered by us. The values of the average random errors ϵ for differences of the corresponding column and also the value of the total amplitude of their variation, A, are also given in the table. The errors and weights of the individual time services were calculated on the basis of Moscow Time Bureau data. An increase of the ΔU_A differences with time indicates that the earth's rate of rotation increases in an odd year with respect to an even year or that a given group is shifted eastward. The reverse is observed in even years. One can trace in Fig. 1 the general run of the differences ΔU_A for the four groups during all four periods. We will initially discuss some peculiarities of the variation of the differences ΔU_A in each of these periods separately.

It is evident from Table 1 and Fig. 1 that in 1957 the earth's rate of rotation changed by small jumps with respect to 1956. The greatest similarity is noted between the ET and WE groups. Both the American groups are more similar to one another than to the Eurasian groups. For example, in July-August, October and November they are of a similar nature regarding the behavior of ΔU_A, while the nature of the behavior of ΔU_A is just the opposite for the Eurasian groups. Comparing among themselves the variation in longitude of the /33 ET group with respect to the three remaining groups (it is not difficult to determine them, having obtained the differences of the corresponding columns of Table 1), we find that the smallest oscillation in longitude ($0^s.007$) was with reference to the WE group; for the NA group it is three, and for the SA group it is even four and half times greater. The variations in longitude for the NA group exceed the mean errors by a factor of three, and the SA group exceeds the mean errors by a factor of four. All this agrees well with the concept of deformations of the earth's crust increasing with distance.

Value of the Differences ΔU_A in $0^s.001$ Table 1

Month	1957 – 1956				1959 – 1958				1961 – 1960				1963 – average for 1962 and 1964			
	ET	WE	NA	SA	ET	WE	NA	SA	ET	WE	NA	SA	ET	WE	NA	SA
Jan.	+10	+4	+2	− 6	− 8	− 7	−18	− 8	− 3	− 1	− 4	−17	−23	−13	−23	−21
Feb.	+13	+8	+2	+ 9	− 9	−13	−11	− 7	− 2	− 1	+ 5	−18	− 9	+ 3	− 8	− 9
Mar.	+10	+9	+7	+ 6	− 6	−11	−10	−14	− 2	+ 1	+ 7	−15	+ 6	+17	+ 5	+15
Apr.	+ 8	−1	+10	+ 5	+ 7	0	+ 1	− 4	+ 1	+ 4	+ 9	− 7	+ 3	+20	+ 6	+10
May	+ 7	−1	+14	+12	+11	+10	+ 8	+10	+ 2	+ 5	+17	−10	+ 9	+18	+ 6	+20
June	+ 1	−5	+11	+ 6	+11	+16	+10	+10	− 5	+ 3	+14	− 5	+12	+15	+ 5	+18
July	− 8	−9	+ 7	− 5	+10	+17	+ 7	+17	− 5	− 2	+ 8	− 2	+ 8	+ 8	− 1	+10
Aug.	+ 1	−2	+ 6	− 6	+13	+16	+ 5	+ 7	−10	− 8	0	− 8	− 8	+ 8	− 1	+ 6
Sept.	+ 8	−1	+11	− 8	+12	+12	− 1	+ 6	−21	− 8	− 8	−11	−10	− 4	− 5	0
Oct.	− 1	−9	+11	+15	− 5	− 1	− 5	+ 5	− 9	− 8	− 2	− 6	−11	− 9	−10	− 9
Nov.	+ 8	0	+ 7	+ 7	−11	− 9	− 8	− 2	− 5	− 8	− 2	− 8	−20	−16	−18	−12
Dec.	+ 1	0	+10	+12	−22	−15	−10	0	− 8	− 2	− 2	−14	−17	−22	−20	−13
ε	±2.1	±2.2	±3.7	±3.5	±2.0	±1.4	±2.6	±2.8	±1.9	±1.2	±2.2	±2.4	±2.0	±1.2	±1.1	±2.5
A	16	18	12	21	35	32	28	31	28	18	21	16	35	42	29	41

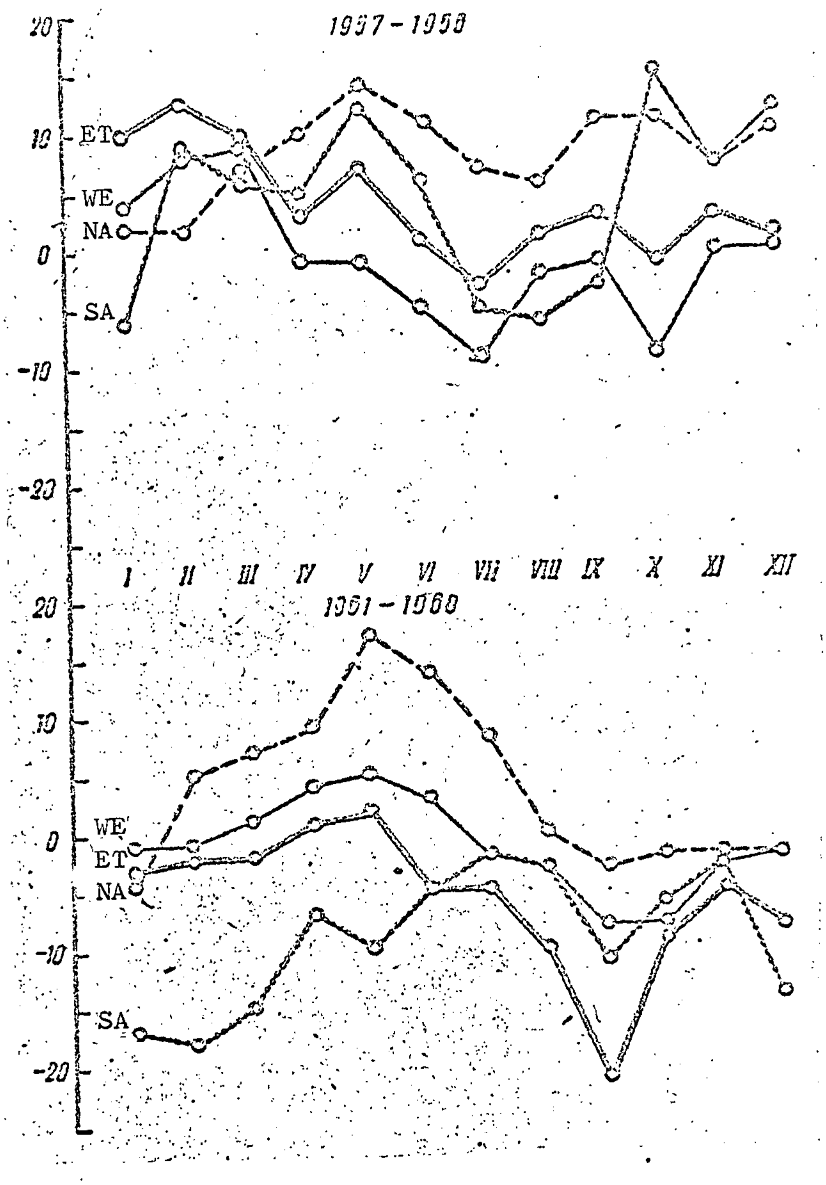

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Figure 1. Value of the difference ΔU_A

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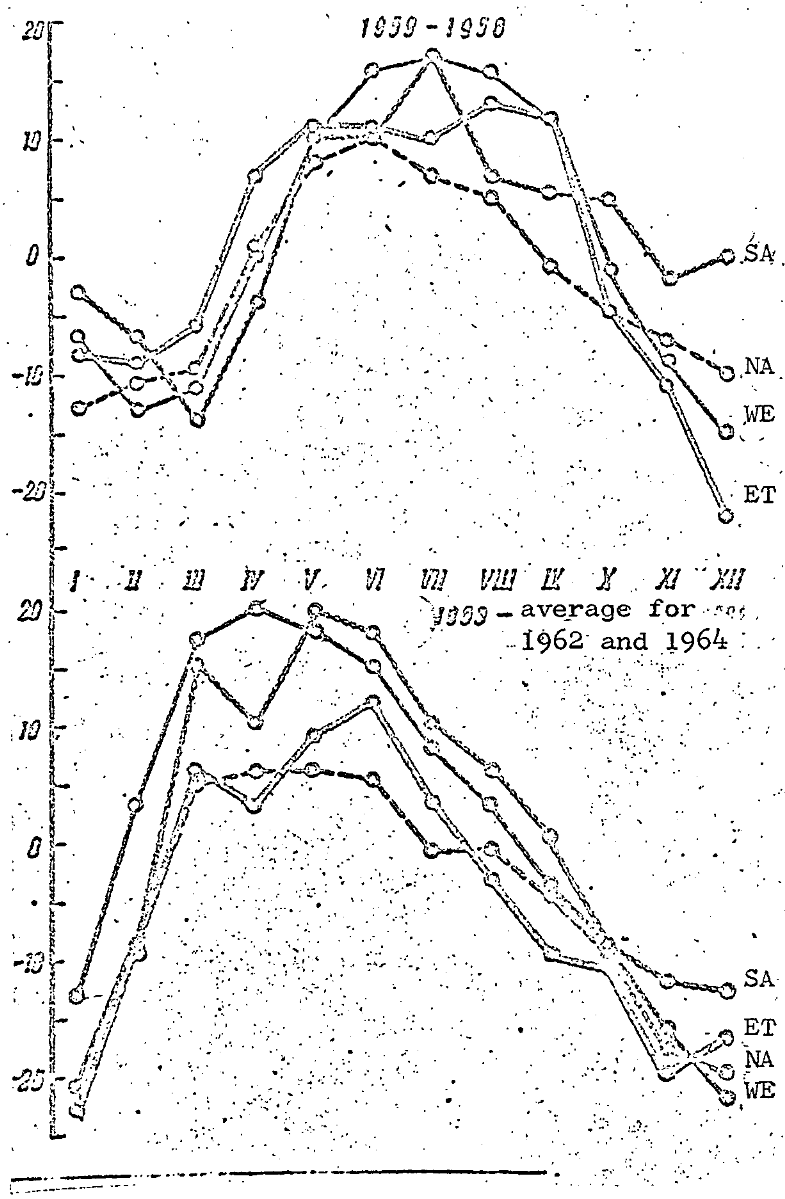

for the four groups of time services.

In 1959 a large anomaly detected by A. Danjon [12] was observed in the seasonal variations in the earth's rate of rotation. As shown in the reference [5], the phase of the seasonal annual term was shifted by a whole month, which was evidently associated with the early spring in northern Eurasia. As a result an anomalous seasonal wave, only two times smaller in amplitude than normal, arose in the differences of the UT2 instants between 1959 and 1958. Therefore, a comparison of these differences for the different groups permits judging to a certain extent the relative variations of longitudes between them and for a normal seasonal wave. If the force changing the earth's rate of rotation is applied to Eurasia and the earth's crust is deformed, then it should be expected that the amplitude of the oscillations for the Eurasian groups will be larger than for the other groups and will lead them in phase. The amplitude A for the ET group is noticeably larger than for the other groups. Regarding phase, the ET group precedes them all, and behind it are the WE and NA groups; the most distant group, SA, appears to be the latest, which completely agrees with what is expected. The variations in longitude of the ET group are somewhat larger here with respect to the remaining groups than in the preceding period. For the WE groups they are equal to $0\overset{s}{.}014$, which exceeds the mean error by a factor of three.

Particularly large anomalies were not observed in the variations of the earth's rate of rotation in 1961 and 1960. Here the large (about $0\overset{s}{.}02$) deviation of the ΔU_A values for the NA group from January until May is interesting. The variation in ΔU_A of the SA group from March until April occurred at a still greater rate, but in May a discontinuity occurred in the opposite direction. A comparison with other data shows that these anomalous movements of the American continent occurred in 1960 and not in 1961. Consequently, it moved westward, approaching the Great Pacific Rift of the earth's crust. The idea automatically arises about the connection of these motions with the catastrophic Chilean /37
earthquake in May of 1960. The large deviation of the ET group in September is also interesting. In magnitude it exceeds the mean error by approximately a factor of seven. The variations of longitude of the ET group are rather large with respect to the remaining groups and exceed the mean errors by several times.

The year 1963 is especially interesting. At its very beginning the earth's rate of rotation about its axis sharply increased, and in the course of the next eight months the duration of the day increased 0.9 milliseconds, according to D. Yu. Belotserkovskiy's [2] data. Thus, in 1963 relatively large variations in the earth's rate of rotation took place. Acceleration of the earth's rotation at the start of the year was detected by Japanese scientists [13], who ascribed it to the influence of an anomalous atmospheric circulation. Since this occurred in the winter, when most of the solar energy is absorbed by the southern hemisphere, one can assume that a major exchange by rotational moments also occurred there. The data of Table 1 confirm this: the sharpest increase in the earth's rate of rotation occurred from January until March for the SA group. It was at least 20% larger than for the other groups. The unusually good agreement of the curve for the ET groups and both American groups from January until March is very interesting. An explanation of this agreement naturally follows from the concept assumed by us of a connection between seasonal variations in the earth's rate of rotation and deformations of the earth's crust. The winter months correspond to the earth's slowest rotation around its axis (we digress here from the effect of the semiannual term, which has little connection with atmospheric circulation). Consequently, in the winter, Eurasia, to which the force of atmospheric circulation which retards the earth's rotation is applied, should be located in its most western position, and America, which lags behind it because of inertia, should be located in its most eastern position. Because of the anomaly of atmospheric circulation in the winter months of 1962-1963, a force accelerating the earth's rotation was applied to South America, i.e., moving it eastward, but since it was already located in its most eastern position, then the corresponding shift was negligible. On the other hand, becuase of the acceleration of the earth's rotation, Eurasia should have, based on inertia, been shifted westward, but since it was already in its most westward position, then the shift here was negligible. The behavior of the WE group, which is larger than in other periods, is anomalous in this period. It deviates from the adjacent ET group. We will dwell on this problem later. /38

To provide a more objective comparison of the degree of similarity of the run of ΔU_A for the various groups, the sums of the squares of the differences $\Delta\Delta U_A$ for the ET groups and the three remaining groups are calculated by us on the basis of the data in Table 1. Of all the differences between groups the average annual difference was provisionally eliminated. In a similar fashion we compared the most distant group SA with all the remaining groups. The results are presented in Table 2. It is evident that in the first three periods the degree of similarity between the groups depends specifically on the distance between them. This regularity is destroyed in the anomalous fourth period. Here the greatest similarity is observed between the ET group and the American groups. If we take the sums of the squares of the differences for all four periods Σ_4 and divide them by the distances in kilometers between the centers of the corresponding time service groups, then we find Σ_4/d, which is presented in Table 2. They are similar to one another, which confirms the concept of deformations of the earth's crust. Their relative size should increase in proportion to the distance between the groups. This regularity is well confirmed both for distances from the ET groups and for distances from the SA group. It is interesting that the total sum of the squares of deviations of Σ_5 for each period proves to be relatively small in those periods when large variations in the earth's rate of rotation occur, and it is especially small in the last period.

Table 2

Sums of the Squares of the Differences $\Delta\Delta U_A$ /39

Group	1957--1956	1959-1956	1961-1960	1963-1962 avg. for & 64	Σ_4	$\frac{\Sigma_4}{d}$
$[ET-WE]^2$	63	232	140	354	789	0.215
$[ET-NA]^2$	614	414	388	128	1544	0.167
$[ET-SA]^2$	824	962	952	137	2875	0.201
$[WE-SA]^2$	951	532	600	451	2594	0.235
$[NA-SA]^2$	496	326	782	249	1858	0.234
Σ_5	2498	2466	2862	1819		
$\sum_{n=1}^{n=11}[ET_{n+1} - ET_n]^2$	191	652	375	732		
$\frac{1}{2}[\Delta_{ET} + \Delta_{WE}]$	17	33.5	18	38.5		
$\frac{1}{2}[\Delta_{NA} + \Delta_{SA}]$	16.5	27	18.5	35		

The four periods considered differ strongly from one another in size and in nature of the variations in the earth's rate of rotation. It is possible to assume conditionally as a measure of these variations the sum for each period of the squares of the differences of successive months for the ET group, namely, $\sum_{n=1}^{n=11}(ET_{n+1}-ET_n)^2$. It is given in Table 2. One can use for this purpose half the sum of the amplitudes, $\frac{1}{2}(A_{ET} + A_{WE})$ or $\frac{1}{2}(A_{NA} + A_{SA})$, which are also presented there. As is evident from Table 2, the sum of the squares of the differences $\sum_{n=11}(ET-WE)^2$ is almost directly proportional to the quantities $\sum_{n=1}^{n=11}(ET_{n+1}-ET_n)^2$, i.e., the larger the oscillations in the earth's rate of rotation, the poorer is the agreement between the ET and WE groups. It is very difficult to explain this fact by errors in the observations. In our opinion the most probable explananation is a completely solid connection between the continental blocks of Western Europe and Eurasia. The earth's crust in Europe is fractured by earthquakes and has breaks, as a result of which the Western European block can be shifted within the limits of several meters relative to the Eurasian continent. If the earth's rate of rotation changes little, then the relative position of the blocks is maintained. In case of strong oscillations in the Earth's rate of rotation, especially if one takes into account the fact /40
that the forces of atmospheric circulation applied to both continents can be different, the relative shift of the blocks increase significantly.

One should also give attention to one peculiarity of the run of ΔU_A for the WE group. It is evident in the last three plots of Fig. 1 that it is distinguished by a more regular behavior than the run of ΔU_A for the other three groups. It resembles a sine curve for the 1959-58 period and a hyperbola for the 1963 period, which is an average for 1962 and 1964. The curve for the WE group is relatively smoother for the 1961-60 period. The curves for the ET group are flattened in the first two cases, and flatness is characteristic of the NA and SA groups for the 1964 (the average of 1962 and 1964) period. If one proceeds from the concept of the motion of blocks, then it is possible to conclude that the WE block moves more freely, while the other blocks are limited in their displacements. This is completely possible, since Europe is located at about the middle of the earth's land hemisphere, while Asia abuts against its eastern edge and America against its western edge into the deep Pacific rifts of the earth's crust, evidently restricting the most rigid part of the earth's crust in the ocean hemisphere.

It was pointed out in P. S. Vornov's paper [4] that the direction of the shear deformations for Western Europe coincide with a geographic parallel, while for Asia and America they form angles of about 45° with a parallel. This should facilitate the shifting of the WE block in case of variations in the earth's rate of rotation. It is possible, therefore, that A. Danjon has succeeded exactly in representing variations in the earth's rate of rotation based on Paris observations by parabolas no higher than the third order. As is evident from Fig. 1, it is significantly more difficult to represent the observations of the other groups in such a manner. Attention is also drawn to the fact that the peaks at the maxima of the curves for the 1959-58 and 1963 (the average for 1962-1964) periods for the WE group agree exactly with the depressions in the curves of the ET group. The size of the peaks is correlated with the size of the depressions. Actually, if one determines them relative to adjacent months, then, based on absolute size, the depressions are twice as large as the peaks in both cases.

As a possible explanation of this, one can advance the following hypothesis: upon a movement towards the east, the Eurasian block is easily thrust against the Pacific rift of the Earth's crust; sliding away from it, it collides with
the Western European block adjacent to it. As a result, the blocks separate in /41
different directions, i.e., the Eurasian again approaches the Pacific rift, and the Western European is shifted westward.

It is evident from Table 2 that in contrast to the ET and WE groups the smallest deviations between the American groups occur precisely during those periods when the variations in the earth's rate of rotation are a maximum (the second and fourth periods). The largest differences between them is observed for the variations in the earth's rate of rotation in the third period, which are average in size. We propose that this is explained by the location of

America between the Pacific deep fracture on the west and the Atlantic rift fracture on the east. In case of large oscillations in the earth's rate of rotation, the American blocks appear to be clamped either to the western to the eastern fracture, and bec se of this they are fixed with respect to one another.

In connection with what has been discussed, it is interesting to compare the relative immobility of the individual blocks of the earth's crust on the basis of our data. To get a complete picture, we add data on Africa (one time service in Algeria), Australia (one time service at Mount Stromlo), and Japan (two time services: at Mizusawa and Tokyo). The average amplitudes A of the shifts, including the variations in the earth's rate of rotation and the variations in longitude for the last three periods, are as follows:

	ET	WE	NA	SA	Africa	Australia	Japan
A	31	29	24	29	42	31	23
ϵ	±2	±1	±2	±2	±2	±5	±2

In the first period there were no observations in Africa, and they were very inaccurate in Australia. As is evident, Africa possesses the largest mobility, being located at the center of the earth's land hemisphere and surrounded on all sides by the rift fractures. Japan and North American have the smallest mobility, being located on the periphery of the land hemisphere and, evidently, more restricted in their displacements by adjacent blocks. The difference of the average annual displacements between Africa and Japan reaches 8 meters, and it is very difficult to explain it by errors of the observations. The result obtained confirms the hypothesis of mobility of the blocks in the earth's land hemisphere.

In conclusion, we compare, on the basis of the data in Table 1, the vari- /42 ations in the duration of the day during a year for all four groups in all the periods. For this we use the first and last rows of Table 1, separating the corresponding differences into 335 days, which is the interval of time between them. In addition, it is necessary to take into account the relative variation in the duration of the day based on a comparison of the Moscow Time Bureau's cumulative instants with atomic time for the same dates. The variations in the duration of the day in fractions of a millisecond are presented in Table 3 for all periods along with their mean errors.

Table 3

Variation in the Duration of the Day for the Observed Periods

Group	1957–1956	1959–1958	1961–1960	1963 – avg. for 1962 & 1964
ET	$+0^{\mathrm{ms}}.492$	$+0^{\mathrm{ms}}.096$	$-0^{\mathrm{ms}}.063$	$-0^{\mathrm{ms}}.107$
	± 9	± 8	± 8	± 8
WE	+0.477	+0.078	−0.076	−0.059
	± 9	± 6	± 5	± 5
NA	+0.441	+0.045	−0.084	−0.095
	± 16	± 11	± 9	± 5
SA	+0.411	+0.045	−0.087	−0.110
	± 15	± 12	± 10	± 10

We turn our attention now to the definite regularity in the first three periods: the ET group has the largest increase in the duration of the day, and it is rather close to the value of the WE group and less than the values of the NA and SA groups. The earth is twisted under the influence of a forces applied to Eurasia. It is difficult to explain the run of these differences by errors of observations. For example, in the first period the differences ET – NA and ET – SA are two and even three times greater than the sums of the mean square errors. The regular run of the variations in the duration of the day confirms the hypothesis of deformations of the earth's crust associated with variations in its rate of rotation. The last period appears here to be anomalous, for which possible causes have been discussed above. Summing up, we arrive at the conclusion that comparatively short-coperiodic variations in the longitude of individual blocks of the earth's crust actually exist and can exceed several meters in magnitude. In our opinion the interaction of atmospheric circulation with the earth's rigid surface and the inertial forces arising upon variations in the earth's rate of rotation caused these longitude variations.

N. Stoyko showed in one of his papers [9] that variations in the difference in longitude between Europe and North America exist with amplitudes of several meters and a period equal to the solar activity cycle. He found that near minimum Europe deviates eastward from America and near maximum, westward.

It is interesting to check his results against the new data published by the Moscow Time Bureau from 1933 until 1961. For this we have used data only of the four European time services, namely, Greenwich, Neuchâtel, Paris, and Uccle, and four American time services, namely, Buenos Aires (geodetic), Washington, Ottawa, and Rio de Janeiro. These eight time services were selected because they have operated continuously during the entire period indicated, which permits hoping for great stability of the system of their observations, /43
which is vitally important in the present case. Sporadic variations in their longitudes were also taken into account from the Moscow Time Bureau data and the reference [20]. The results of all the time services were taken to have equal weight. The average values of the difference in longitudes (Europe - America) for the last three cycles of solar activity, arranged as a function of the phase of the solar cycle relative to its maximum, are presented in Table 4. The data of Table 4 correspond to the middle of each year. They confirm the

Table 4

Difference in Longitudes between Europe and America for Years of Solar Activity (in milliseconds).

Years			$\Delta\lambda$	$\odot$
1933	1943	1953	+ 21,3	m
1934	1944	1954	+ 25,7	m
1935	1945	1955	+ 25,7	
1936	1946	1956	+ 26,7	
1937	1947	1957	+ 35,0	M
1938	1948	1958	+ 32,7	
1939	1949	1959	+ 24,7	
1940	1950	1960	+ 27,3	
1941	1951	1961	+ 26,7	

results of N. Stoyko: near maximum, Europe is shifted westward relative to America, and near minimum, eastward. To obtain a more accurate determination of the amplitude of the longitude variation, it is better to use the differences in longitudes corresponding to the nearest maxima and minima with an interval in all of 3-4 years, which significantly decreases the effect of fluctuating systematic errors.

To determine the mean square error separately for each cycle, we have calculated the deviations of the time services' longitudes from their mean systems. The values of the total amplitude of the variation in the longitude difference between Europe and America from maximum to minimum solar activity are presented in Table 5. The agreement of the individual values for the three cycles is very good, but the random errors are rather large. Nevertheless, the error of the weighted mean is almost three times smaller than the value found for the amplitude. It is natural to suppose that the same mechanism is operating /44 here as for the seasonal longitude variations, i.e., the effect on Eurasia of atmospheric circulation with a period equal to the solar activity cycle. But it should also cause variations in the earth's rate of rotation with the same period. The maximum shift of Eurasia eastward from America will correspond to the earth's maximum rate of rotation, and the maximum shift westward, to the minimum rate of rotation. On the basis of the Moscow Time Bureau data, the variations in the duration of the day ΔT were calculated with respect to atomic time in hundred-thousandths of a second from July 1955 to January 1965. We have used V. I. Turenko's data [9] for their distribution in the earlier years, when there was no atomic time service. He investigated the behaviors of three first-class quartz clocks of the Kharkov State Institute of Measures and Measuring Devices, which operated continuously from 1951 until 1959, and he obtained the "aging" equation for these clocks, taking into account all factors capable of affecting their running. They were compared with atomic clocks for the common years from 1955 until 1959, which permitted finding the corrections to their running with respect to atomic time and expressing the variations in the duration of the day obtained on the basis of V. I. Turenko's data in the atomic time system. The variations in the duration of the day ΔT found in this manner with respect to atomic time are given in Table 6 in hundred-thousandths of a second from 1951.5 until 1964.5.

Table 5

Variations in the Longitude Difference between Europe and America

Cycle	$\Delta\lambda$ $M-m$
1933 - 1937	$+0^{s}.0115 \pm 82$
1944 - 1947	$+0^{s}.0126 \pm 77$
1954 - 1957	$+0^{s}.0091 \pm 50$
Weighted mean	$+0^{s}.0104 \pm 37$

Table 6

Variations in the Duration of the Day with Respect to Time (in units of 0.01 milliseconds

Year	ΔT	$\odot$
1951.5	+89	
1952.5	+90	
1953.5	+65	
1954.5	+60	m
1955.75	+74	
1956.5	+80	
1957.5	+135	M
1958.5	+139	
1959.5	+131	
1960.5	+119	
1961.5	+111	
1964.5	+129	
1963.5	+152	
1964.5	+194	

In view of the presence of irregular variations in the earth's rate of rotation, it is best to use the values for the minimum of 1954 and the maximum of 1957, which are closest in time, to determine the amplitude of the variation in the duration of the day. Then we obtain that the difference in the duration of the day between maximum and minimum solar activity is equal to +0.75 milliseconds. If we take into account the linear variation between the closest years of the identical phase in the cycle, 1951.5 and 1961.5, then this difference decreases to 0.68 milliseconds. The result obtained confirms the assumption that the earth rotates more rapidly near the minimum of solar activity and more slowly near the maximum. Of course, this conclusion, drawn on the basis of one solar activity cycle, with the inclusion, moreover, of quartz clocks, is insufficiently reliable. We used D. Brouwer's [11] data as a control. He indicates that starting from 1932 the results of meridian observations of the moon nearly coincide with observations of stellar occultations by the moon. Consequently, the accuracy of the observations of the moon has increased. Sliding two-year averages (in hundred-thousandths of a second) of the value of the variation /45
in the duration of the day, calculated on the basis of the reference [11], are given in Table 7 for the period of time for 1932.5 to 1949.5. It is evident from the table that the dependence of the duration of the day on solar activity

Table 7

Two-year Averages of the Variation in the Duration of the Day (in 0.01 milliseconds)

Year	ΔT	$\odot$	Year	ΔT	$\odot$	Year	ΔT	$\odot$
1932.5	-28		1938.5	-28		1944.5	-18	m
1933.5	-25	m	1939.5	-28		1945.5	-18	
1934.5	-28		1940.5	-10		1946.5	-10	
1935.5	-28		1941.5	-16		1947.5	-11	M
1936.5	-26		1942.5	-17		1948.5	-15	
1937.5	-20	M	1943.5	-10		1949.5	-12	

is expressed definitely enough in the second cycle (1944.5-1947.5). The /47
difference in the duration of the day between maximum and minimum solar activity is equal to +0.7 milliseconds, which is very close to the preceding result for the 1954.5-1957.5 cycle. This difference is equal to +0.5 milliseconds for the first cycle (1933.5-1937.5), but the distortions in the curve for the variation of ΔT and the errors associated with them are very great. It is difficult to estimate the values of the mean square errors of the differences found, since not only the errors of the observations but also the irregular variations in the earth's rate of rotation appear here. Nevertheless, the rather close agreement of the values found speaks in favor of their reality.

It is interesting to compare the relative sizes of the deformations in the earth's crust for the annual and 11-year periods. If interaction of atmospheric circulation with the earth's circulation is the reason for them, as was explained earlier, the size of the deformation should be proportional to the size of the variation in the earth's rate of rotation or the variation in the duration of the day. Based on the Moscow Time Bureau data, the variation in the duration of the day is equal to 0.86 milliseconds for the annual seasonal term. It is possible to find from N. Stoyko's [18] data that the amplitude of the total variation in longitude between Greenwich and Ottawa during the course of a year is about $0^s.016$. Hence we find the following ratios of the size of the deformations to the variation in the duration of the day: the annual term is $D/\Delta\Delta T = 0^s.016/0^s.00036 = 18.6$; the 11-year term is $D/\Delta\Delta = 0^s.0104/0^s.00068 = 15.3$. Both the ratios are close to one another, and one could say that they agree within the limits of possible errors. This attests once more to the correctness of the ideas expounded here. Therefore it is possible to draw another interesting conclusion. If one assumes that the ratio of the deformation's size to the variation in the duration of the day, which is equal to 17 (the average of the two values found), maintains its value for various periods of the disturbing force's action, then it is not difficult to show that the relative size of the deformation will increase with a decrease in the period. The papers [3], [6], [10], and [16] confirm the acctual existence of short-period variations in the earth's rate of rotation. A priori considerations, but mainly the presence of sufficiently powerful short-period cycles in the weather, argue in favor of this. /48

Recently the Japanese astronomers S. Iijima and S. Okazaki [14] discovered a two-year component in the variations of the earth's rate of rotation. They did this by comparing the results of observations of six observatories from 1956.9 to 1964.9 with atomic time. In addition, they established a definite connection between the variations in the earth's rate of rotation and the known variations in the velocity of the equatorial stratospheric wind, which has a period in the variations of the earth's rate of rotation is also confirmed by the work of the Italian astronomers E. Proverlio and F. Catra [17].

The question arises whether or not there is a 26-month period in the variations of the difference in longitude between distant time services. We have preliminarily investigated this problem in a simplified manner. To this end, the data of eight observatories (Greenwich, Neuchâtel, Paris, Uccle, Buenos Aires, Washington, Ottawa, and Rio de Janeiro), which in our opinion are characterized by relatively large stability in the system of their observations over lengthy intervals of time, were utilized.

Starting from 1933, the Moscow Time Bureau has published yearly averages of the longitude corrections K_i, corrected for the shift in the earth's pole, for the eight observatories indicated. It should be noted that if a two-year wave actually exists in the variations of the difference in longitudes between any time services, then the existence of a difference $\Delta\Delta K_i$ between the differences of the longitude corrections for these time services ΔK_i in even and odd years is possible in this case.

First we determined these differences $\Delta\Delta K_i$ for the period of time investigated by the Japanese astronomers, 1957 to 1964. The averages of the differences between the average of a group of four European observatories and two North American and two South American observatories, separately and together, are presented in Table 8. (It is taken into account that in 1962 all the time services switched to the new FK4 catalogue and the values of the assumed lonitudes changed.)

Table 8

Differences $\Delta\Delta K_i$ Calculated from the Data of European North and South American Observatories.

Period	4 WE - 2 NA	4 WE - 2 SA	4 WE - 4 A
	0.0010	0.0010	0.0010
1933-1935	+ 4.0	+13.9	+ 9.0
1944-1950	+ 6.7	+ 7.8	+ 7.0
1957-1964	+ 4.8	+ 8.6	+ 6.4
Average	+ 5.0	+ 9.9	+ 7.5
ε	± 0.9	± 2.0	± 0.8

Since the actual period is not two-year but 26 month, then in 13 years, which contain exactly six such periods, the effect in question should repeat itself with a shift in phase by one year (from even to odd). It repeats itself /49 once more in 26 years in the initial phase. Therefore the corresponding values of $\Delta\Delta K_i$ are also given in Table 8 for the periods of time 1944-1950 and 1933-1935, which are spaced 13 and 26 years from the main period. In the last case it was necessary to be restricted to only three years, since the values of K_i for Ottawa and Rio de Janeiro have been published starting only from 1933. The very good agreement of the differences $\Delta\Delta K_i$ for the three different periods of time speaks in favor of the reality of the 26-month period in the variations of the difference in longitude between Western Europe and both Americas.

It is very difficult to explain the very noticeable effect found by any errors of the observations, in particular, by the wind effect.

From our point of view, the most probable explanation is an actual shift of the Western European block relative to the American blocks, which reaches approximately 1.5 meters with respect to North American and 3 meters with respect to South America.

On the basis of what has been stated, it is possible to arrive at the conclude that the earth's crust is by far more mobile than has been assumed. The earth's land hemisphere may be contained within a gigantic bowl bounded by the deep Pacific fractures. It evidently represents the most mobile part of the earth's crust. The individual land blocks are in motion almost all the time. Since these motions are restricted to narrow limits, then they have essentially an oscillatory nature. It is possible to suppose that these /50 oscillatory motions of the individual blocks act as unusual recoil hammers and gradually in the course of many millions of years extend the area occupied by the land continent. These notions are naturally associated with the well-known theory of A. Wegener on the separation of the continents. On the other hand, such continual motions of large blocks of the earth's crust contribute to the accumulation of excess energy in the earth's deep interior. This energy, which is actually of solar origin, is released mainly at the points where the blocks collide and can contribute to a significant local temperature increase in different regions of the earth's lithosphere and mantle, which may in the final analysis be the cause of earthquakes and even of tectonic movements.

The concept which we have expounded here of the motion of continental blocks under the influence of the comparatively small forces produced by atmospheric circulation joins together many scientific problems of the physics of the earth's atmosphere and lithosphere.

We consider that the time has come to begin a systematic investigation of these motions in the earth's upper crust with the help of astronomical obeservations. The most interesting sites on the earth should be selected for this purpose jointly with geophysicists and geologists. Of course, the Moscow Time Bureau data can be used to a certain extent.

A significant increase in the accuracy of the astronomical observations is important for the successful accomplishment of such a task. Some proposals in connection with this occur in our papers [7] and [8]. The following seem particularly important to us: 1) correct selection of a site for establishing an instrument far from disturbing refraction effects; 2) a rational arrangement of the observatory with the use of ventilation which completely excludes intra-observatory refraction, and weakens the influence of the wind effect; and 3) thermal protection of the instrument. In addition, it is necessary to organize special astronomical observations to determine the errors, which depend on the slope of equal-density air layers [8]. Obtaining corrections as accurate as possible to the stellar coordinates [1] remains one of the primary problems as before.

Continuous study of the motions of individual continental blocks is of great scientific interest for geophysics, geology, and seismology, and it can assist in the solution of an important practical problem, namely, the scientifically-valid forecast of earthquakes.

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